Fracture of Human Dentin: Is it Stress- or Strain-Controlled?

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Despite substantial clinical interest in the fracture resistance of human dentin, there is little information in the archival literature that provides for any mechanistic details that can be used to model such fracture. In fact, although the fracture event in dentin, akin to other mineralized tissues like bone, is widely believed to be locally strain-controlled, there has never been any scientific proof to support this belief. This issue is addressed in the present study through the use of a novel double-notched bending test geometry.

Distinction between Stress- and Strain-Controlled Fracture

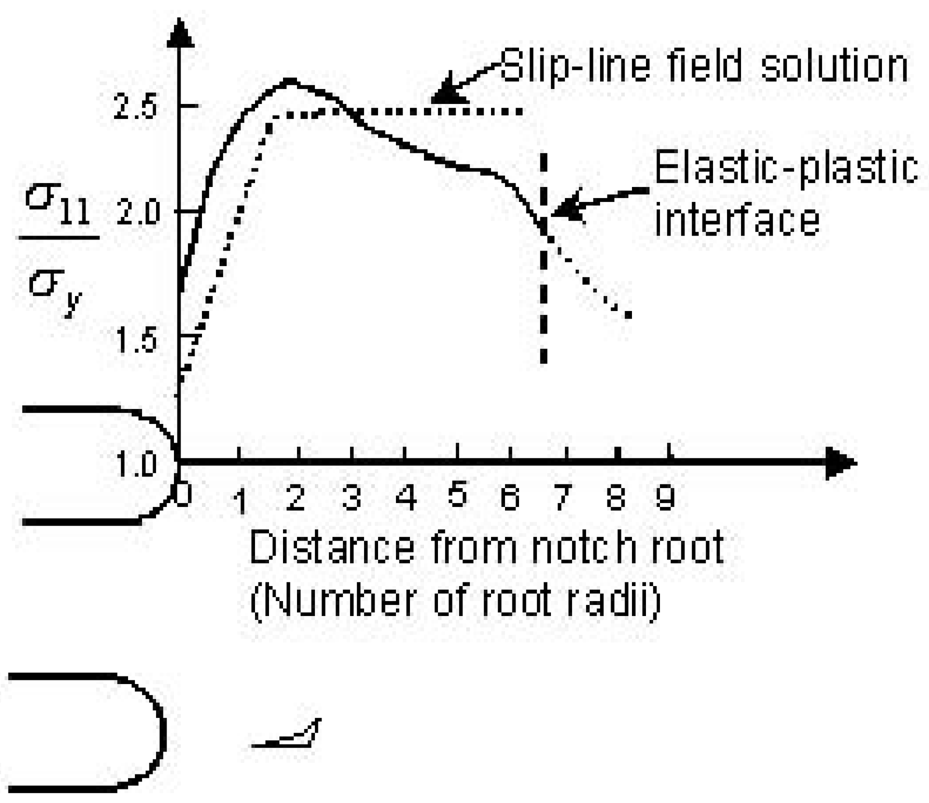
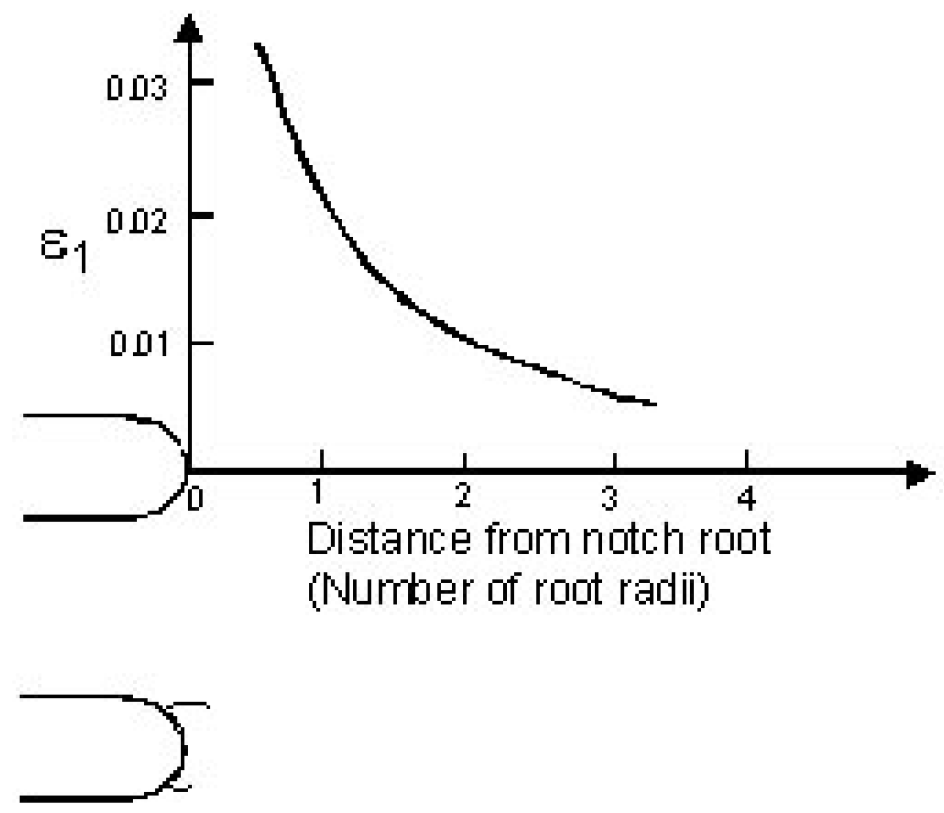


Fig1: Stress (left) and strain (right) distributions, based on slip-line field analysis [Hill R. The Mathematical Theory of Plasticity. Oxford, U.K.: Clarendon Press; 1950.] and numerical computations [Griffiths JR, Owen DRJ. An elastic-plastic stress analysis for a notched bar in plane strain bending. J Mech Phys Solids 1971;19:419-431.], ahead of a "blunt" notch. Also shown are schematic illustrations of possible stress-controlled (left) and strain-controlled (right) fracture mechanisms emanating from such notches. Note for stress-controlled mechanisms, the initial fracture event is ahead of the notch, whereas it is at the notch root for strain-controlled mechanisms.



Double-Notch Bending Geometry

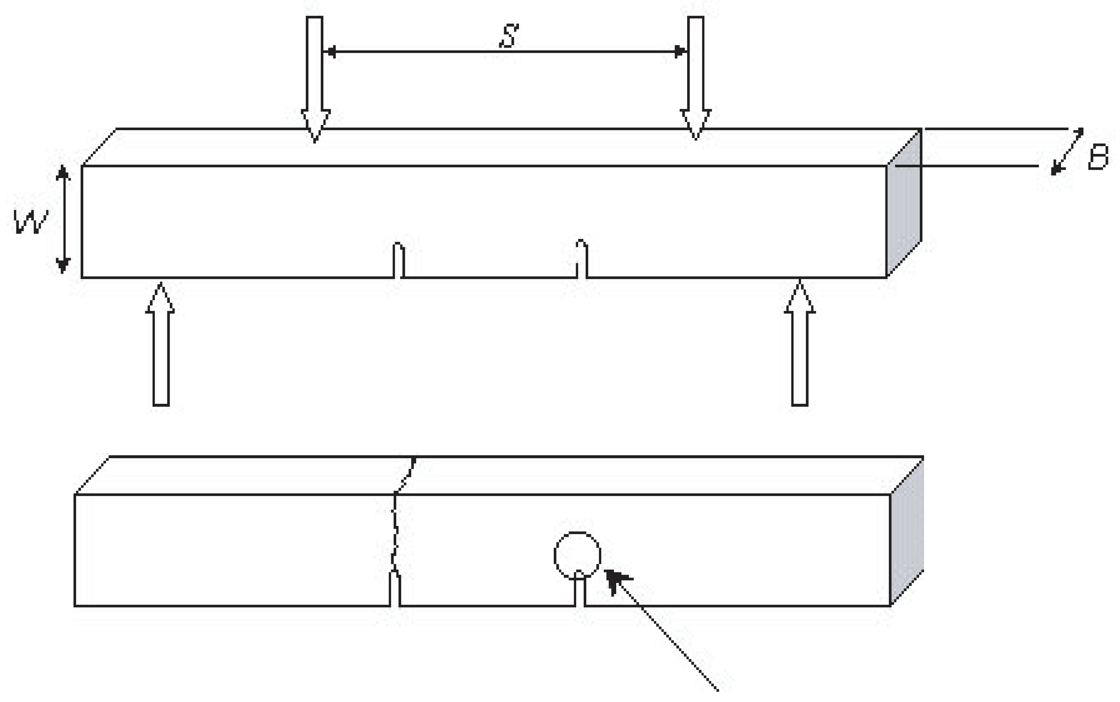


Figure 2: Schematic illustration (top) of the double-notched four-point bend test used to discern whether fracture is stress- or strain-controlled. Between the inner two loading points, the bending moment is constant; thus, when one notch breaks, the other is "frozen" at a point just prior to fracture instability. The region beneath this unbroken notch (below) is then carefully examined to determine the site of the precursor microscopic events involved in the fracture process.

Fracture in Dentin is Definitely Strain-Controlled

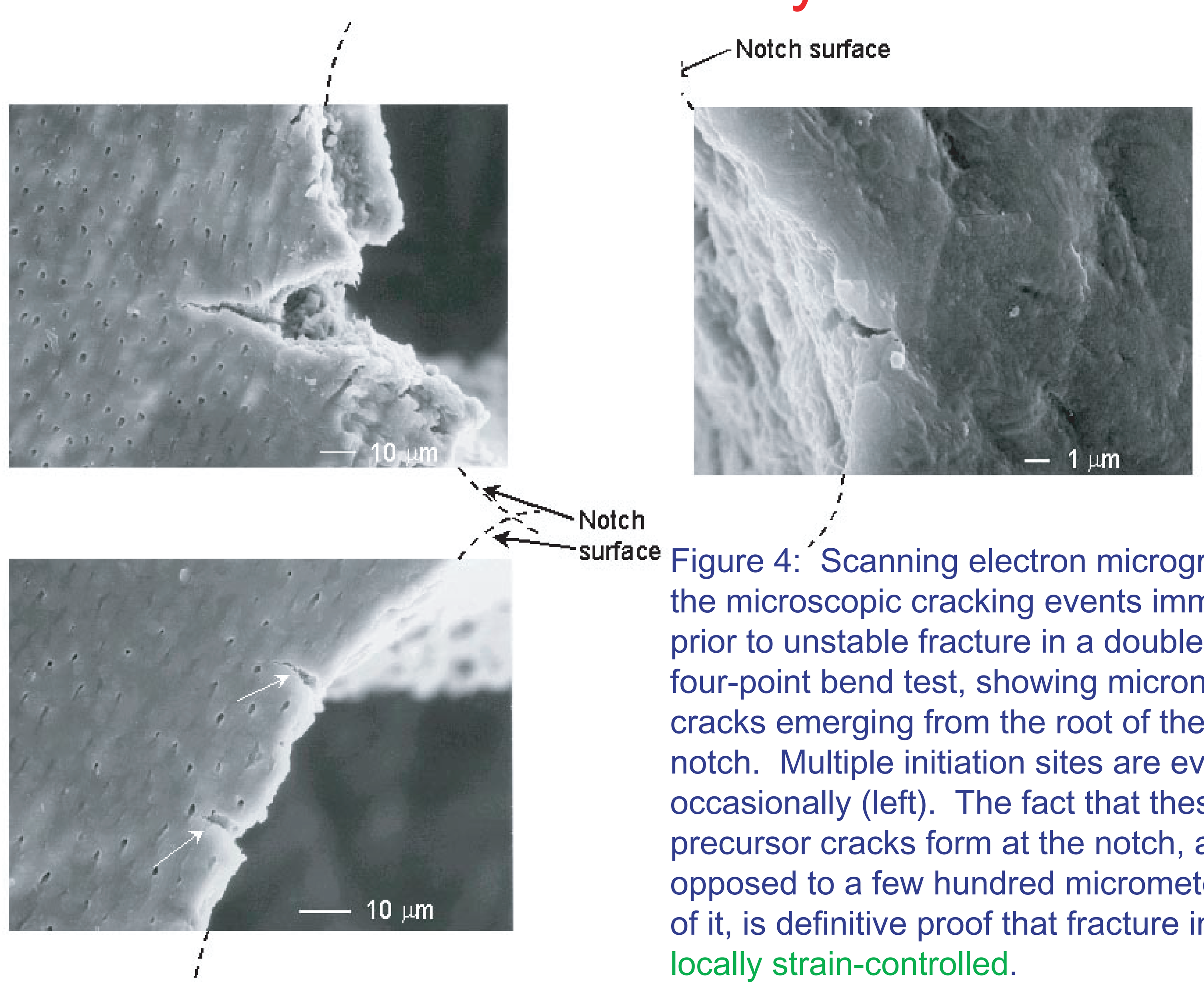


Figure 4: Scanning electron micrographs of the microscopic cracking events immediately prior to unstable fracture in a double-notched four-point bend test, showing micron-scale cracks emerging from the root of the unbroken notch. Multiple initiation sites are evident occasionally (left). The fact that these precursor cracks form at the notch, as opposed to a few hundred micrometers ahead of it, is definitive proof that fracture in dentin is locally strain-controlled.

Notion of Plasticity in Human Dentin

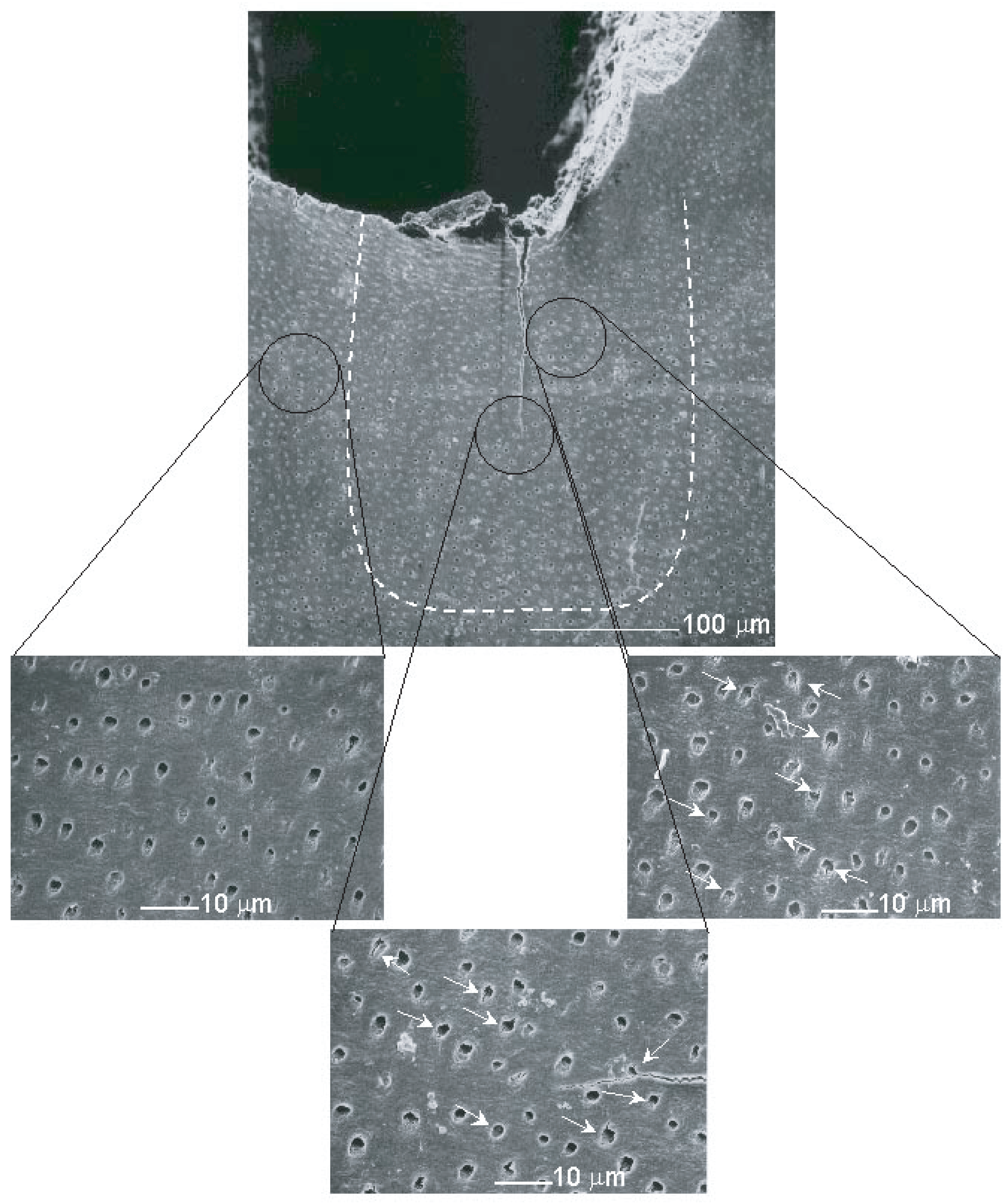


Figure 3: The concept of the double-notch test is based on the premise of inelasticity or plastic yielding, it is important to establish that inelastic deformation occurs in human dentin. Although well understood for traditional materials e.g., in the form of dislocation activity in metals, the mechanism of "yielding" in dentin is far less characterized, but can be considered in terms of regions of "diffuse microdamage", as in bone. Scanning electron micrographs of the concept of a "yielding" or "damage" zone is shown, based on the regions where the peritubular cuffs are cracked. An overview of a crack emanating from a notch, with the nominal damage zone indicated as a dotted line based on the continuum solution for the "plastic-zone" size. Note the extensive cracking of peritubular cuffs in the "damage zone" inside this "damage zone" (indicated by white arrows) and the relative absence of such damage outside the zone.

Crack-Microstructure Interaction in Dentin

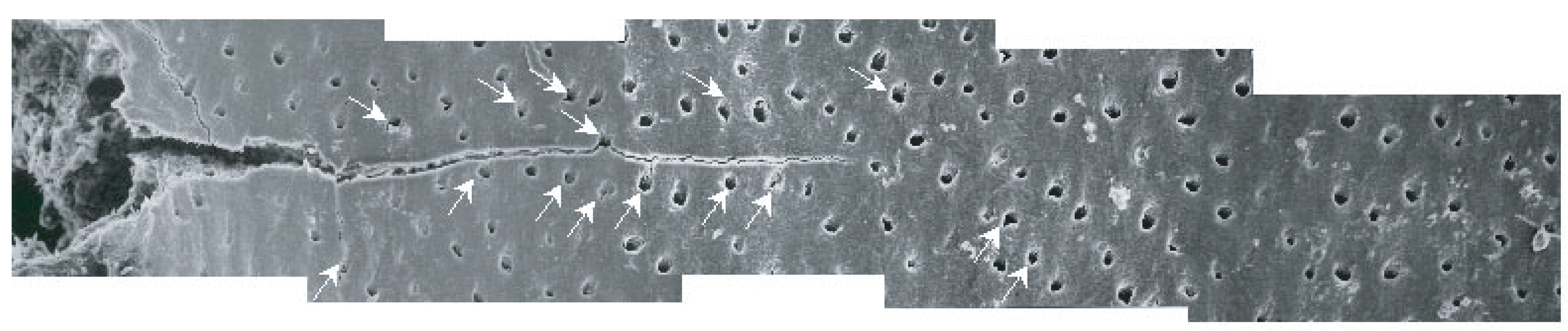


Figure 5: Scanning electron micrographs of a ~200 micron crack emanating from the notch, showing the relationship between the crack path with the salient microstructural features. Note the extensive cracking of the peritubular cuffs (indicated by the white arrows) and the interaction of the sub-cracks with the main crack path. Evidently, crack propagation is not affected substantially by the underlying microstructure.

Recent Publications

Nalla, R.K., Kinney, J.H., and Ritchie, R.O., "On the fracture of human dentin: Is it stress- or strain-controlled?," *Journal of Biomedical Materials Research*, 2002, in review.